KMR SCIENTIFIC ADVISOR

Equatorial Atmospheric & Ionospheric Modeling for Space Surveillance

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Outline

- ➔ Introduction
  - Kwajalein Missile Range (KMR) long range tracking radars
  - Ionospheric correction methods
  - KMR ionospheric conditions
- KMR model overview
- Real-time GPS TEC determination
- Accuracy evaluation
- Summary

ALTAIR/TRADEX Characteristics

ALTAIR
VHF, 158 MHz
UHF, 422 MHz

TRADEX
L-band, 1320 MHz
S-band, 2950 MHz

- **US Army space surveillance and missile reentry vehicle tracking radars**
- **Equatorial location**
- **Two frequency tracking**
  - **ALTAIR: UHF/VHF**
  - **TRADEX: L-band/S-band**
- **Accuracy goal for ionospheric correction:**
  - **Within 6.5 TEC units; 100 m range at VHF or 14 m at UHF**

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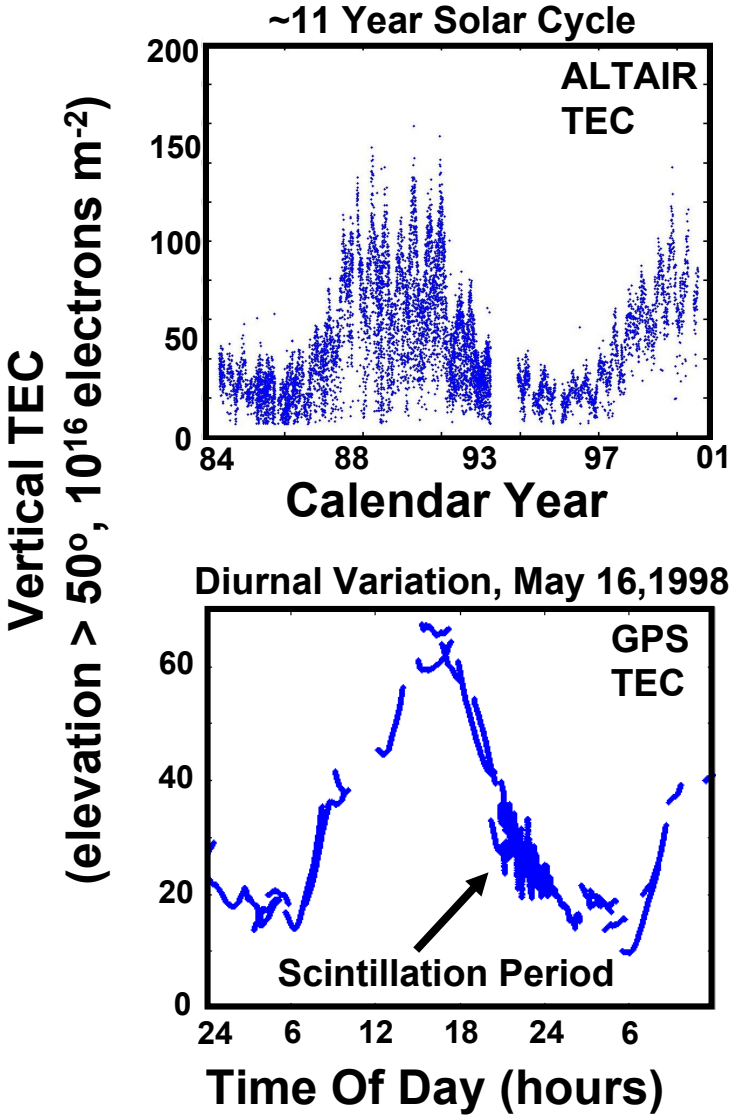
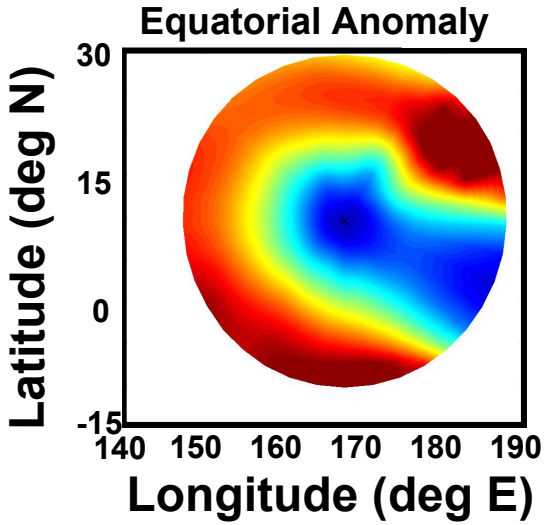
Impact of Ionosphere at KMR



- **Sophisticated modeling technique needed to meet space surveillance accuracy requirements**
- **Solar cycle, seasonal and diurnal enhancements, equatorial anomaly, TIDS, Plumes, E and F-region irregularities and enhanced plasmasphere**



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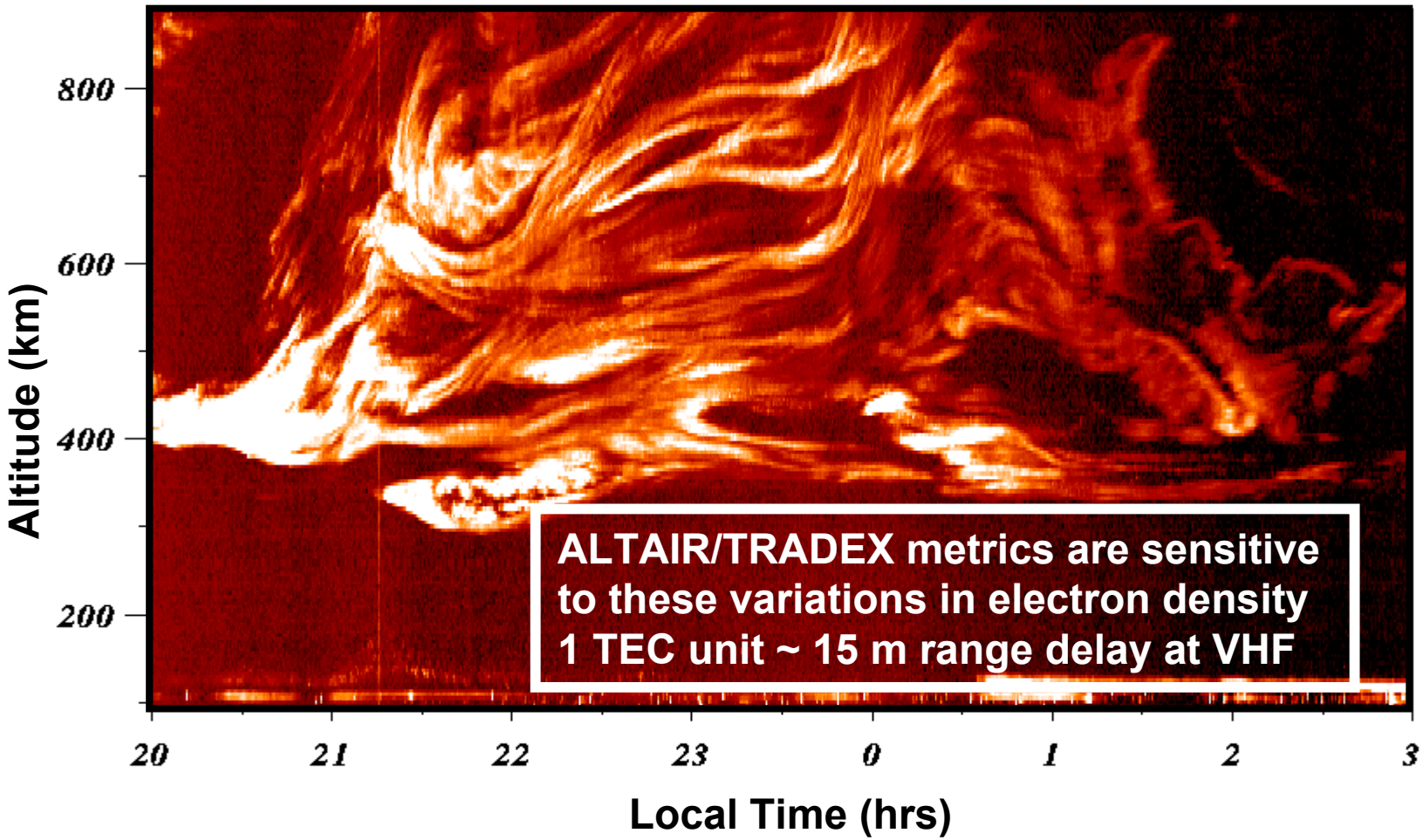
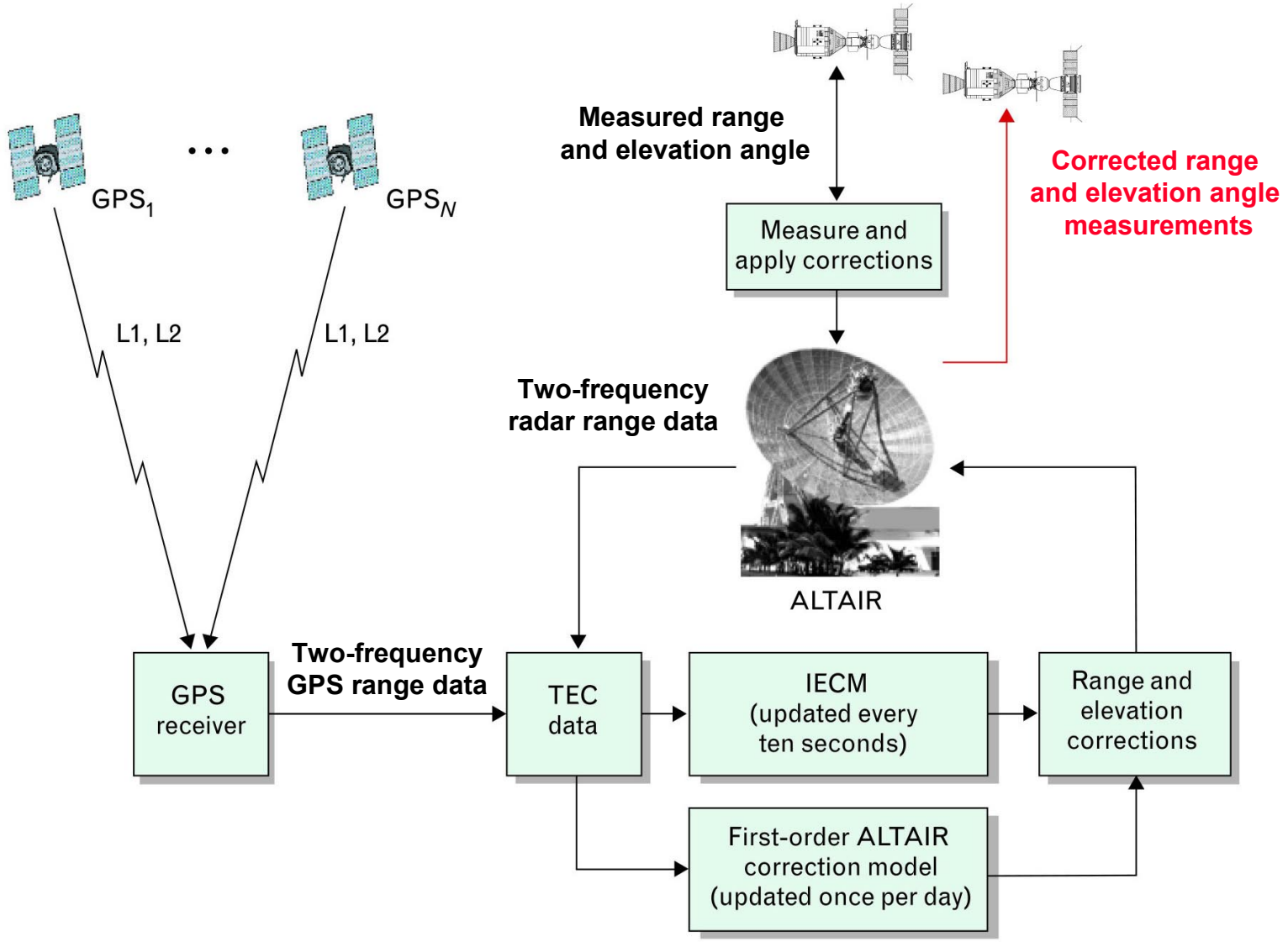
Equatorial Spread-F



Data obtained at Jicamarca Oct 22, 1996 (50 MHz)

Ionospheric Correction Methods



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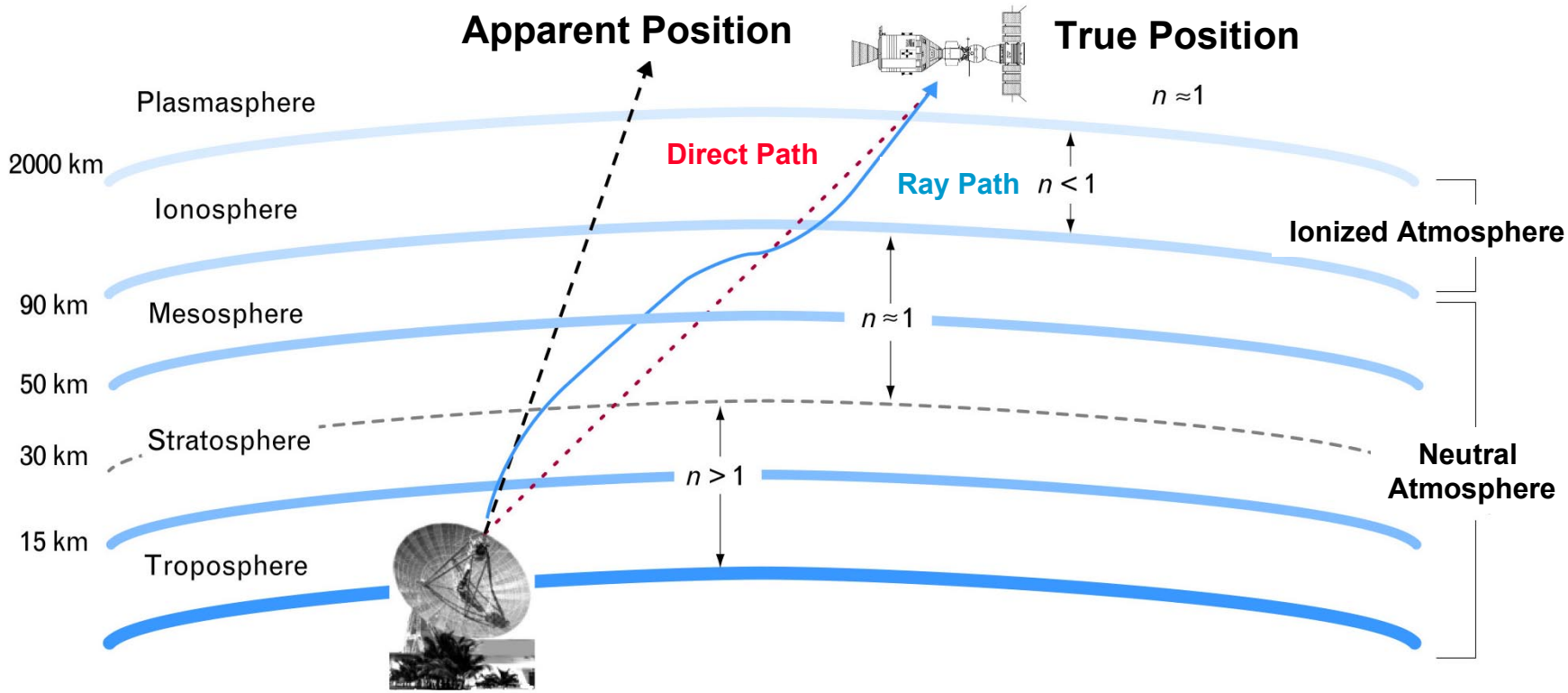
Model Ray Path Geometry



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Outline

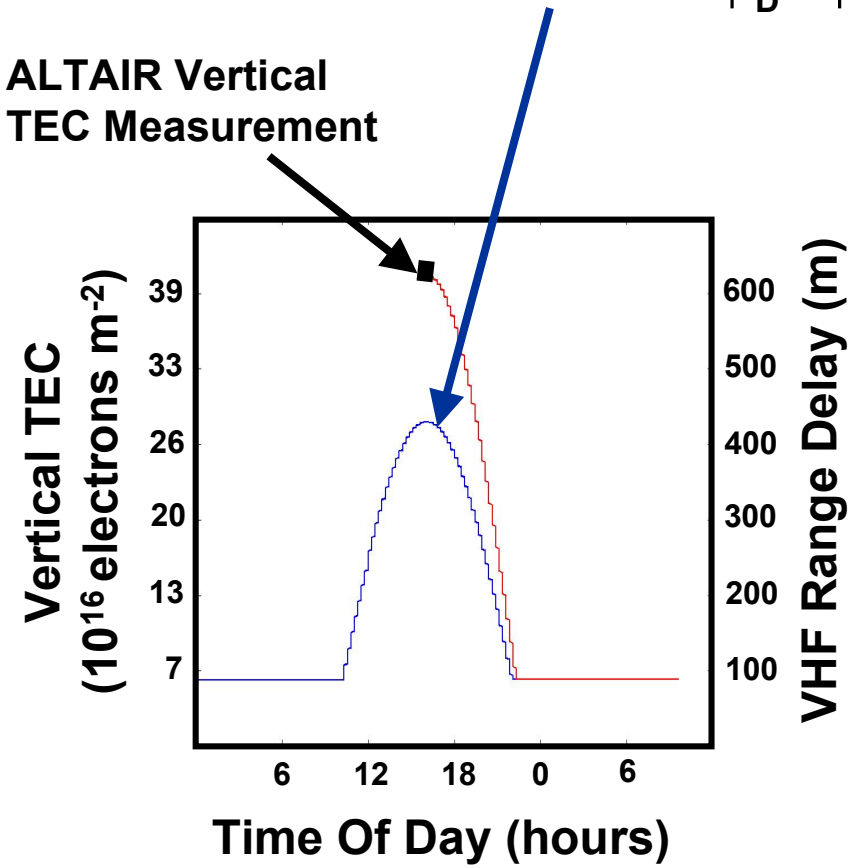
- Introduction
- ➔ KMR model overview
  - Mean Tropospheric model
  - First-Order ALTAIR Ionospheric model
  - New Ionospheric Error Correction Model
- Real-time GPS TEC determination
- Accuracy Evaluation
- Status and summary

Tropospheric Model

- Mean tables are used for all real-time correction
  - Covers 0-90 km altitude, (inert portion)
  - Troposphere, Stratosphere, Mesosphere
- Range and elevation corrections as a function of range and elevation
- Derived from KMR radiosonde data spanning 1967-1976
  - Function of temperature, pressure and relative humidity
- Radiosonde data are collected prior to each reentry mission
  - Post processed to obtain maximum accuracy for reentry data reduction

First Order Vertical TEC Model

$$\text{Vertical TEC} = \varphi_D + \varphi_Y(660. + 740.(\cos(\text{lt} + \text{ha} + \varphi_S))$$



- Maintains knowledge of TEC at ALTAIR's vertical
- Derived from ALTAIR backscatter data
- In use from 1983 to 1998

φ_D = function of day of year
φ_Y = solar cycle amplitude factor
φ_S = seasonal phase term
ha = hour angle of radar pointing
lt = local time

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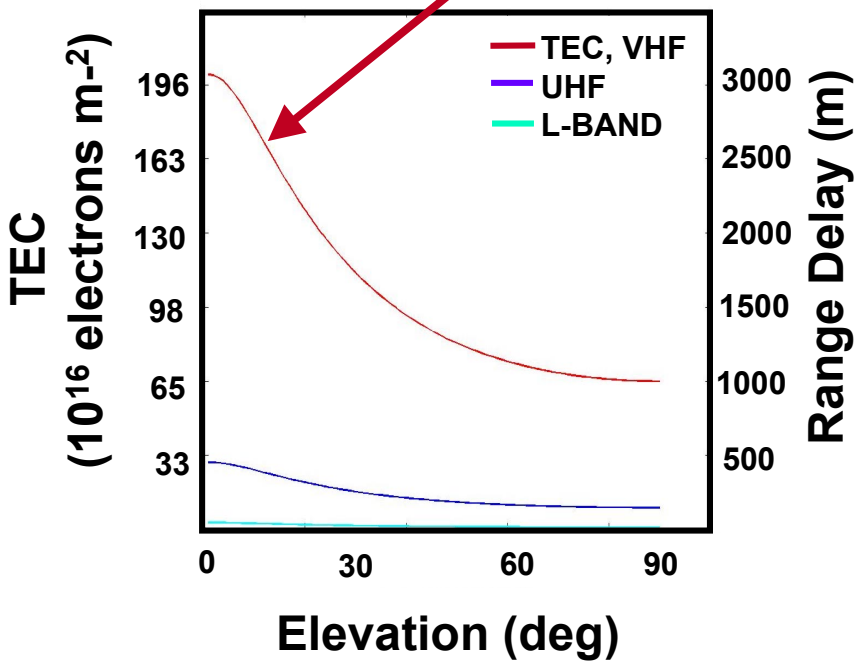
First Order Elevation Mapping Function

$$TEC_{LOS} = TEC_{VERT}(1 - f(el) * fxh)$$



- "Maps" vertical TEC to arbitrary elevation and height
- Derived from multi-frequency reentry mission radar data
- Peak density height fixed at 400 km
- In use since ~1978

TEC_{LOS} = line of sight TEC
TEC_{VERT} = vertical TEC
f(el) = elevation factor
fxh = height scale factor

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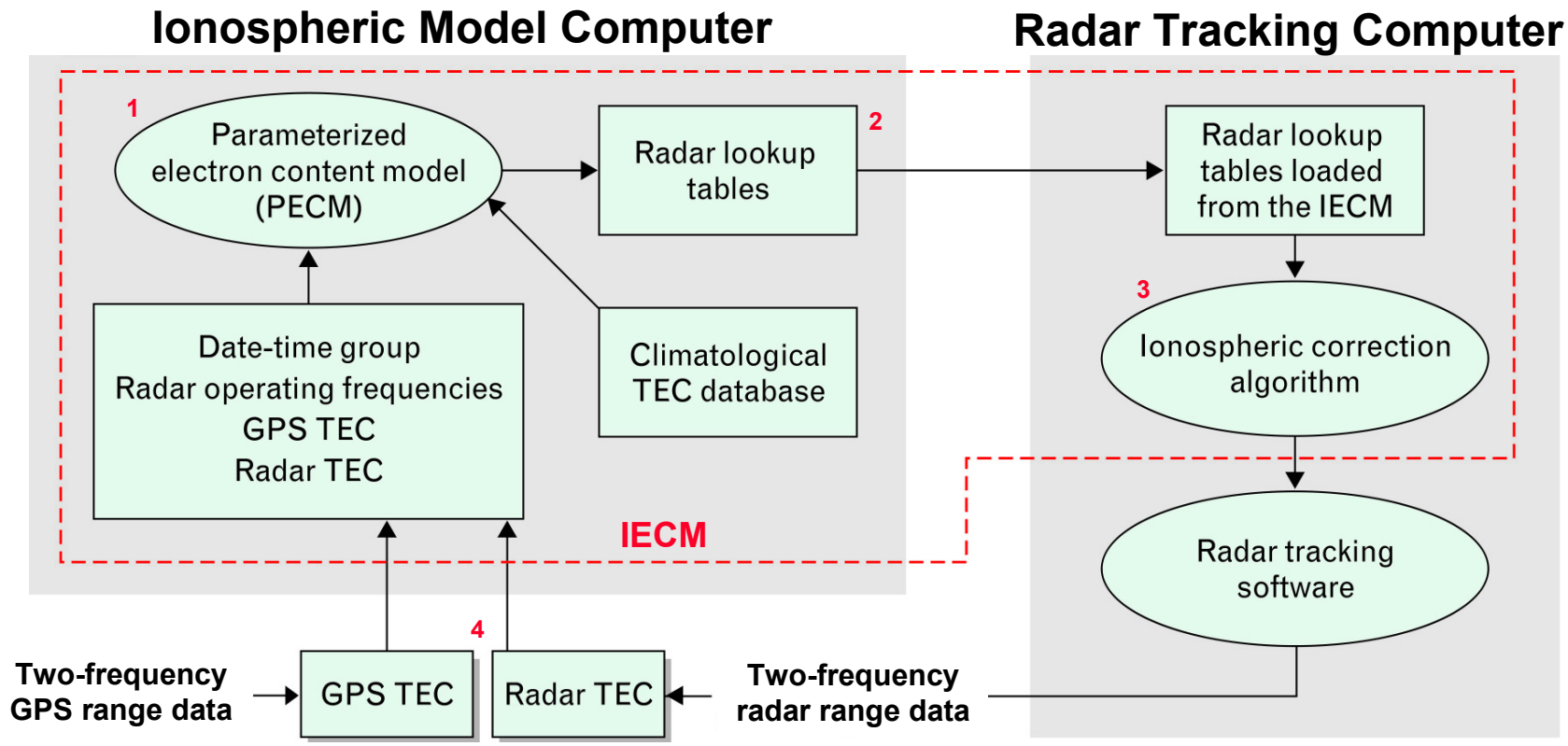
IECM and Radar Architecture



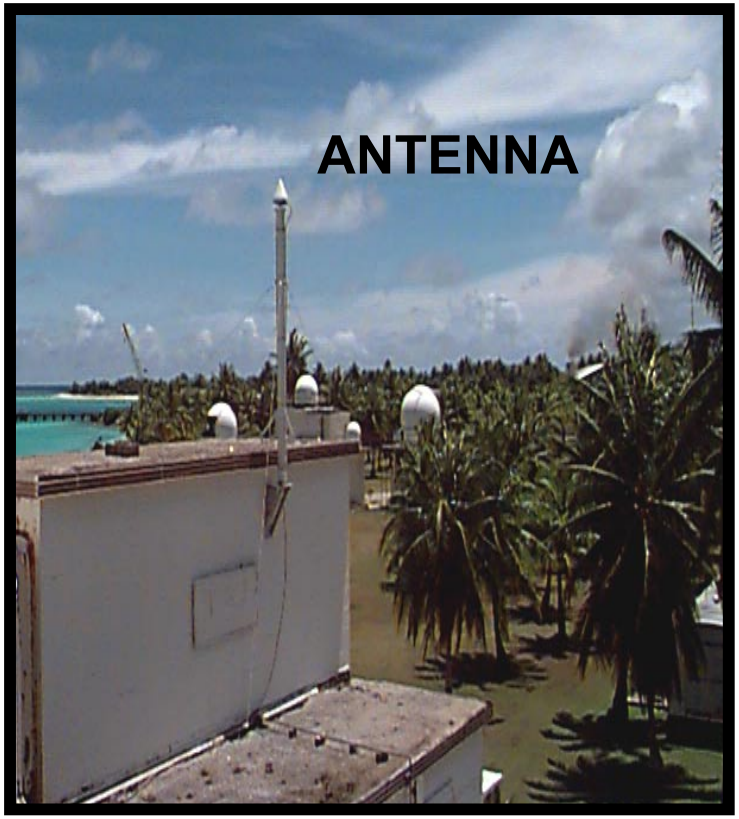
PECM Features

- 540 Base electron content models (ECM)
- ECMs are indexed by solar activity and seasons
- 60 ECMs per day: 30 and 15 minute time separation
- Mean F10.7 value and time used to select specific ECM
- Real-time TEC data are used to adjust the ECMs
- Two dimensional ray trace is performed to produce IS file
  - Troposphere and ionosphere
  - True range and elevation as a function of apparent azimuth, elevation and range

Outline

- Introduction
- KMR model overview
- ➔ Real-time GPS TEC determination
  - Receiver installation
  - GPS TEC determination and calibration
- Accuracy evaluation
- Status and summary

GPS Receiver Installation



- Site survey was executed to determine best receiver location
- Installation chosen to reduce multipath effects
- Temperature controlled
- Installation has proven to be trouble free

Outline

- Introduction
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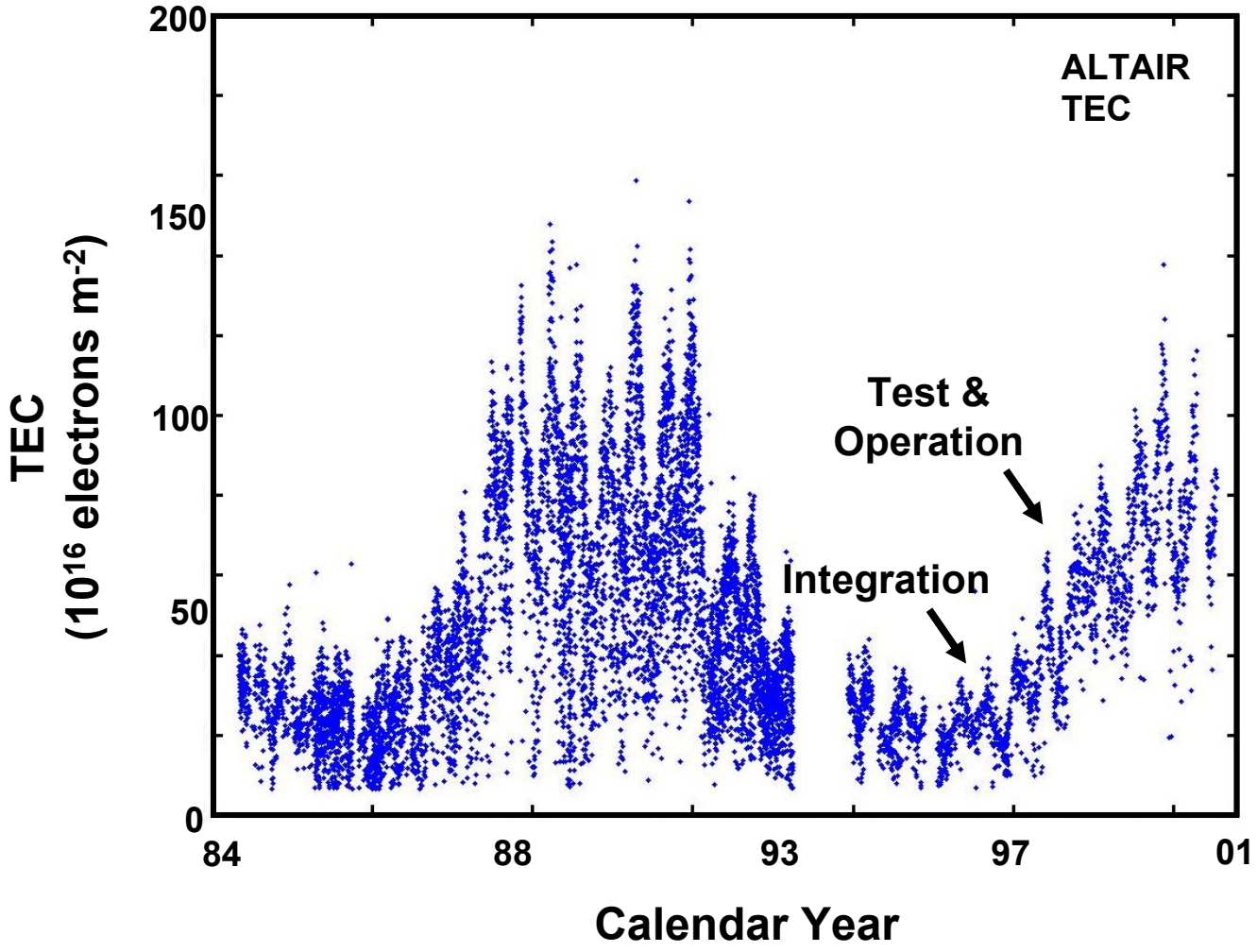
- Real-time GPS TEC determination
- ➔ Accuracy evaluation
  - Radar versus IECM TEC
  - Calibration orbit residual error
- Status and summary

Model Integration and Test



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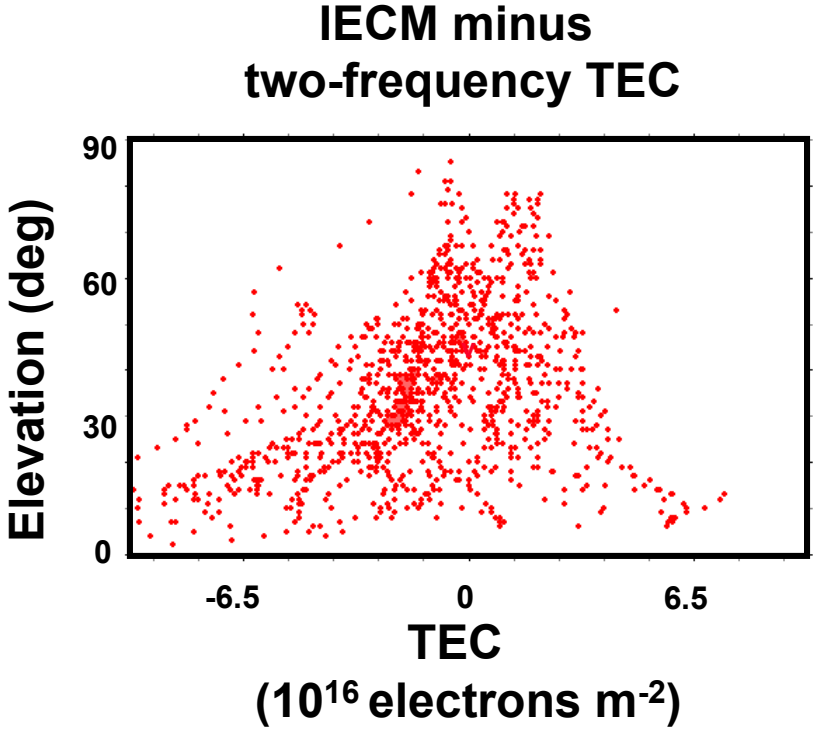
Two Frequency Radar vs IECM TEC



- IECM/GPS versus radar line of sight TEC difference computed
- Data collected during low solar activity at altitudes between 700 km and 1500 km

Results:

- Within 6.5 TEC or 100 m VHF range above 20 degrees elevation

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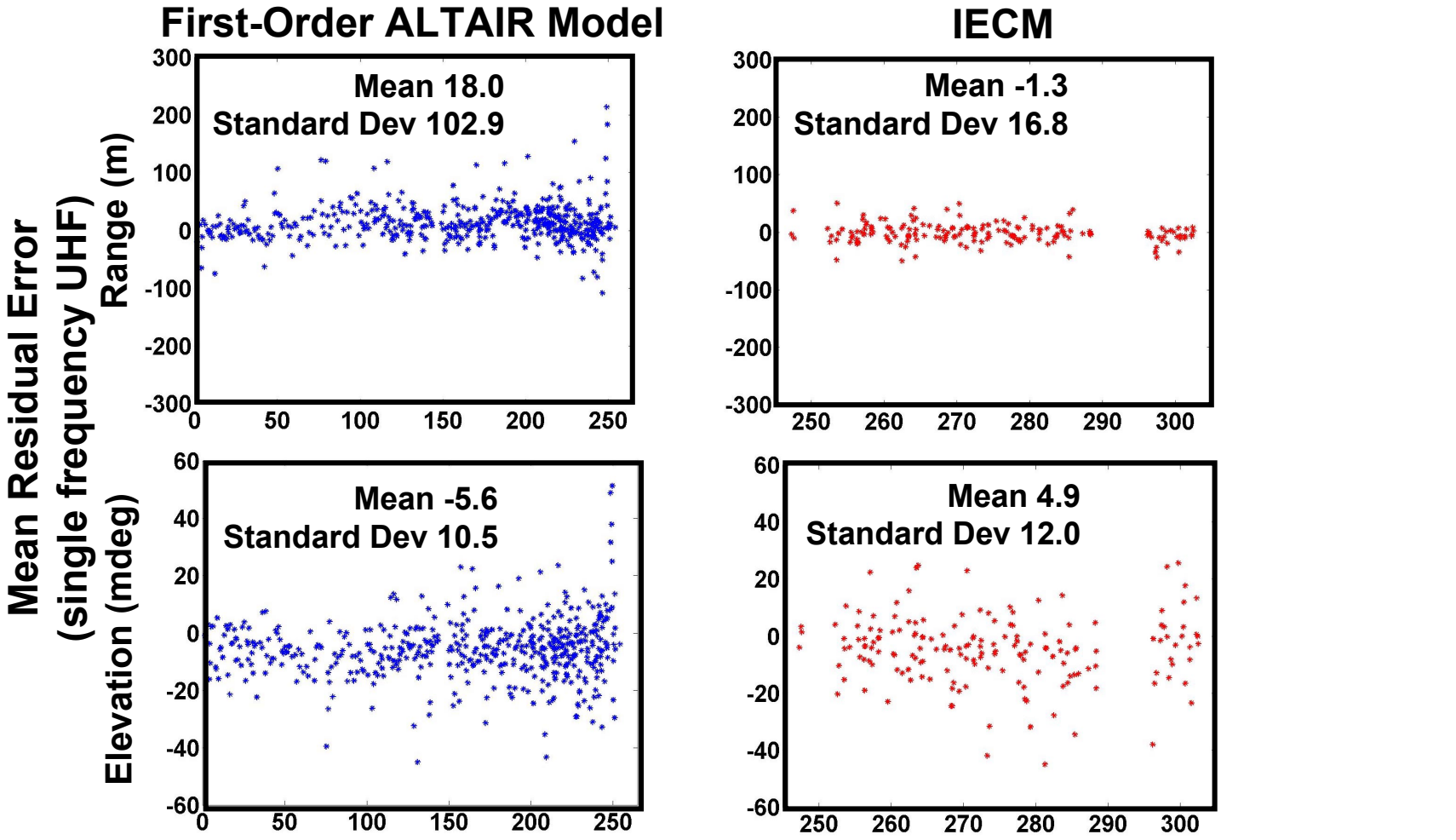
Range and Elevation Measurement Error

Altitude > 5000 km



Calibration Satellites
20026, 19751, 22195, 8820

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Summary

- The KMR atmospheric environment is challenging to model
- The first order ALTAIR model is inadequate
  - Effective only during periods of low solar activity
- The IECM combined with GPS TEC has proven effective
  - IECM is fully integrated and operational
  - Slated for use for the KMR radar modernization effort
- IECM accuracy results
  - Accurate during low and moderate solar activity
  - Significant improvement in single frequency UHF range accuracy at ALTAIR
  - Room for improvement during high solar activity

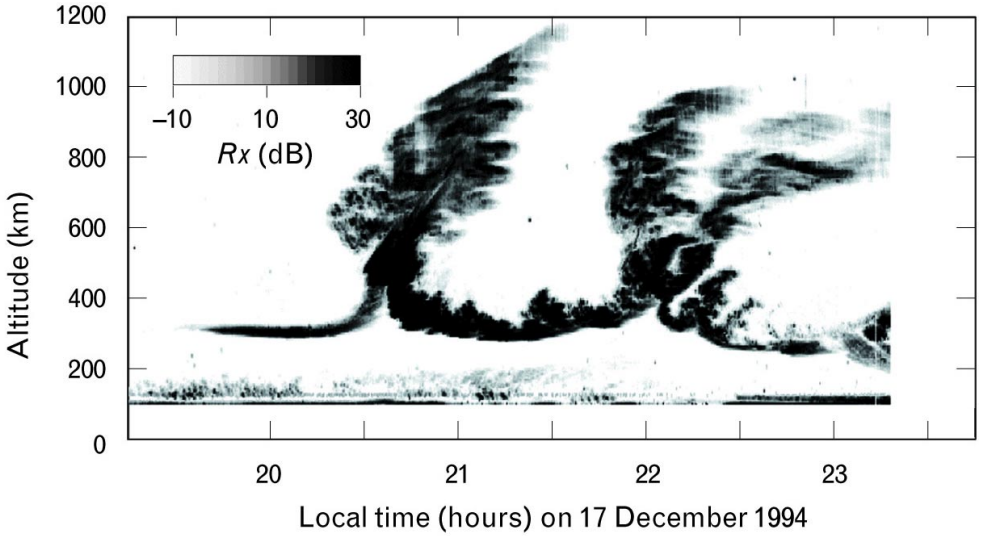
Metric Calibration Satellites

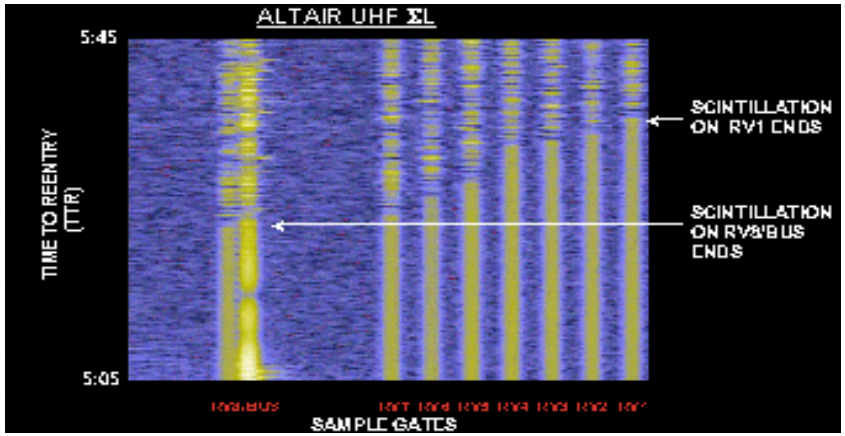
Name SCC #	Semi-major axis (km)	Position Accuracy*
Lageos1 8820	12270.01	~1m
Lageos 2 22195	12162.06	~1m
Cosmos 19751	25503.06	~25m
Cosmos 20026	25499.44	~25m

*Estimate of upper bound

- Precision orbits determined using NASA laser ranging and US Space Command Space Surveillance Network sensors
- Position accuracy smaller than radar measurement error for Lageos 1 and Lageos 2

Radio Frequency Scintillation





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KMR Sensor Network

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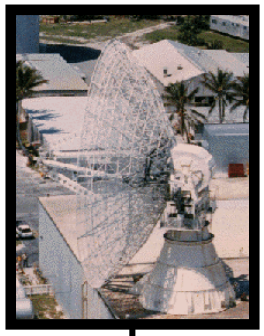
MMW
Ka-band, 35 GHz
W-band, 95 GHz

ALCOR
C-band, 5664 MHz

TRADEX
L-band, 1320 MHz
S-band, 2950 MHz



ALTAIR
VHF, 158 MHz
UHF, 422 MHz

Space Surveillance

Space Command

CHEYENNE MOUNTAIN

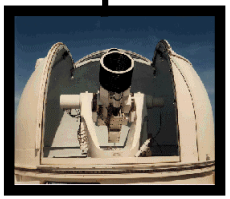
DATA ANALYSIS CENTER

OFF-SITE DATA REDUCTION

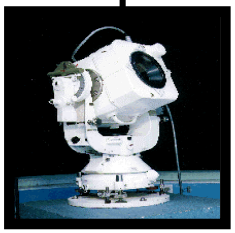
VOICE / DATA

(CONUS LOCATIONS)

RANGE SAFETY



TRACKING OPTICS



BALLISTIC CAMERAS

TM

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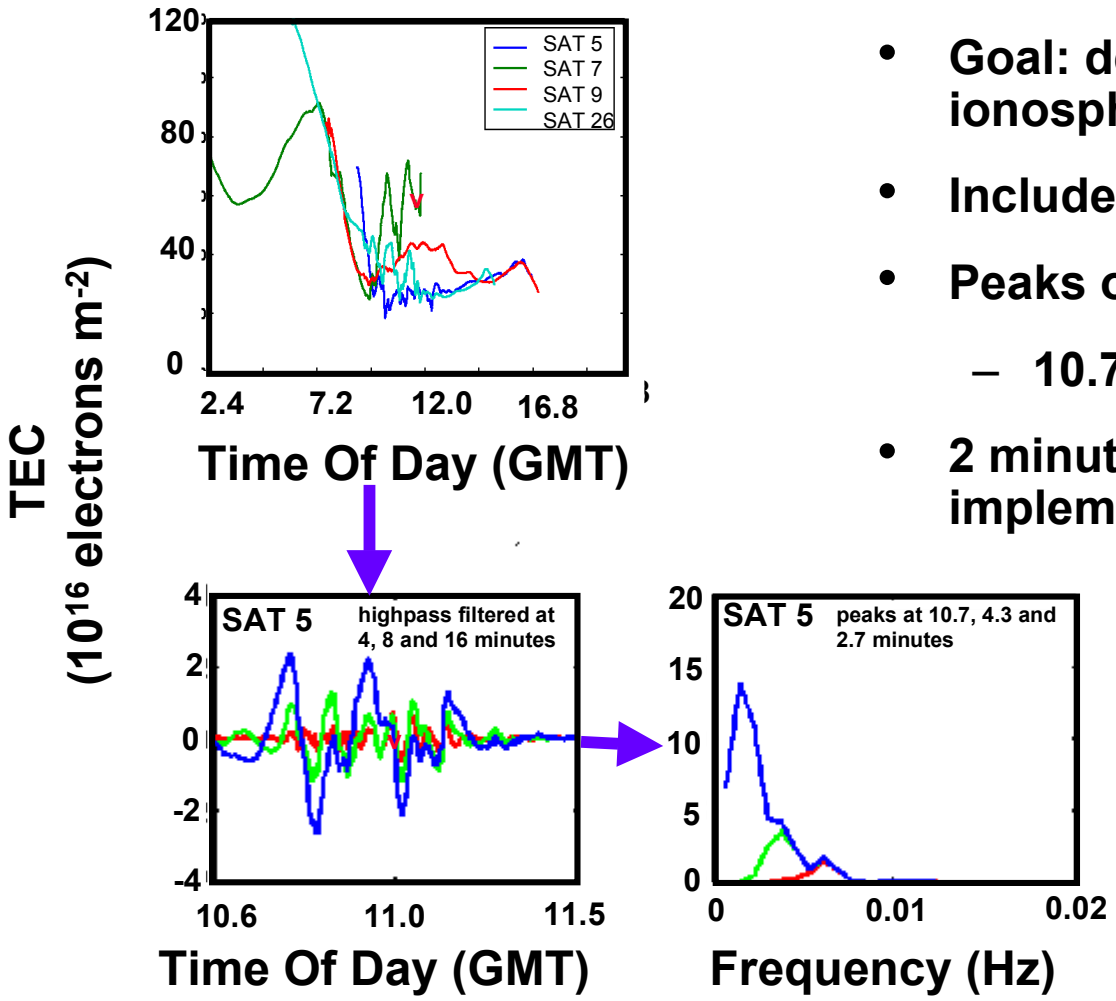
Effect of Ionospheric Instabilities on TEC



- Goal: determine frequency of ionospheric fluctuations
- Included scintillation period
- Peaks occurred at:
  - 10.7, 4.3 and 2.7 minutes
- 2 minute update rate implemented for IECM

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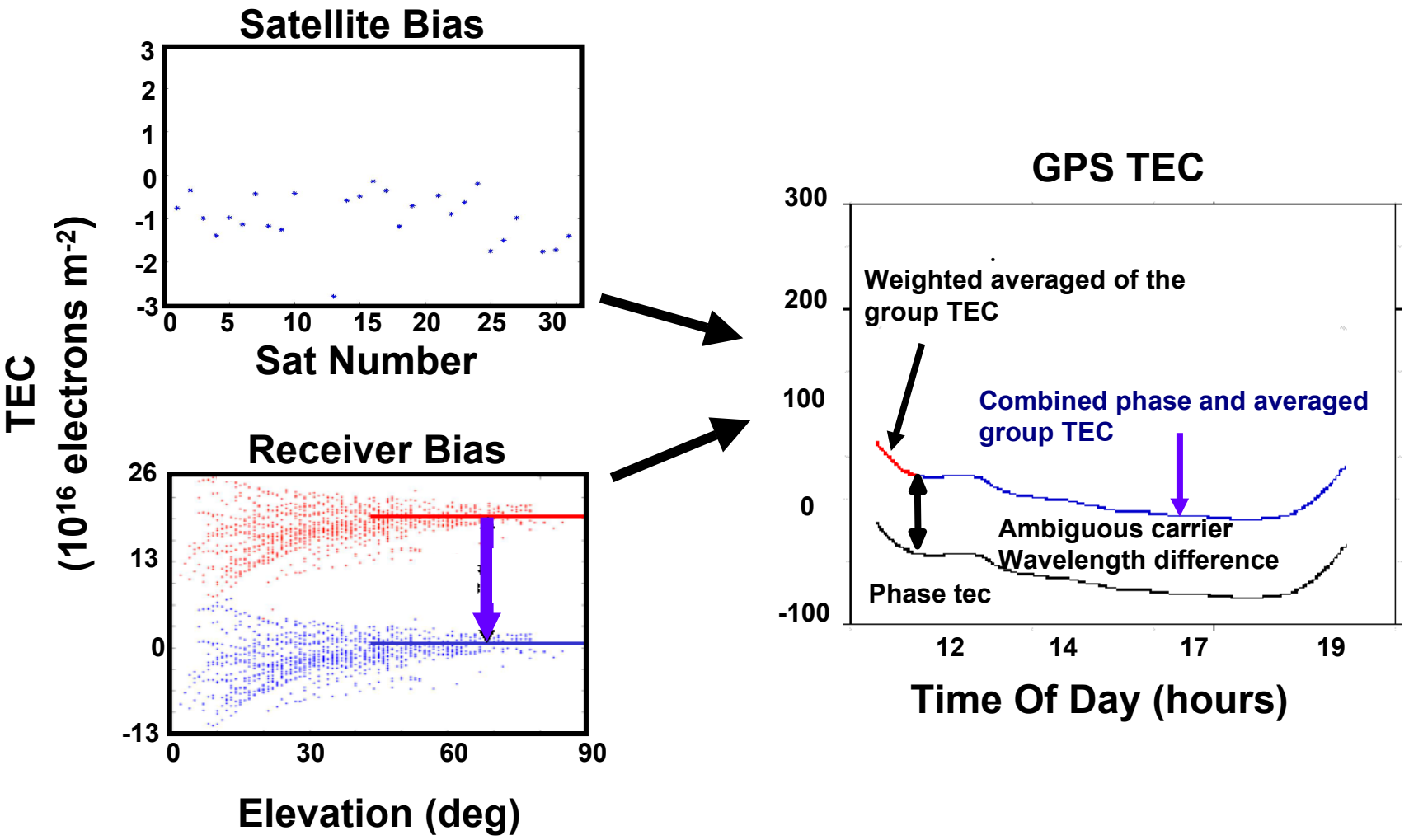
GPS TEC Determination and Calibration



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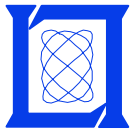
Ionospheric Error Correction Model



- **Parameterized Electron Content Model (PECM)**
  - Base theoretical climatology model
  - Derived from global model PRISM
  - Real time data update algorithm
- **Ionospheric Specification Manager**
  - Manages radar correction table message traffic
- **Ionospheric Correction Algorithm**
  - Used to compute true to apparent and apparent to true range and elevation corrections from correction tables
- **TEC data reduction software**
  - Used to compute *real time* GPS and radar TEC